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Analysis of Defects In Solid Rocket Motors Using X-Ray Radiography

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Abstract

NDE plays a significant role in the evaluation of solid propellants motors. X-ray radiography is one of the most important of all the nondestructive test methods used in this area. To meet the growing and challenging demands of launch vehicle applications, research and development in the field of radiography is improving with modern imaging techniques and new sources of radiation. Defects such as voids, porosity, cracks and debonds are detrimental to the performance of a solid rocket motor. While defects such as cracks and debonds are caused mainly by poor design of the rocket motor, voids and porosity are caused by inappropriate selection of process parameters and conditions. This paper analyzes the radiographic images of defects observed in various solid propellant rocket motors. Defects such as 'void with a crack' were observed in free-standing propellant grains of special purpose motors processed with pvc-plastisol based composite propellant. The shape and orientation could be traced to the high temperature physical curing process, casting technique, viscosity of slurry during casting and the casting set-up configuration. 'Cluster of voids' or porosity observed in some of the rocket motors due to the presence of moisture in the propellant slurry or entrapment of air in the insulation free flap.

This paper deals with the overview of propellant radiography and analyzes the radiographic images of defects observed in various solid propellant rocket motors processed at Vikram Sarabhai Space Centre, Trivandrum.

Key words:

Solid rocket motor, Propellant defects, Radiography, NDT plan

1.0 Introduction

Solid rocket motors provide the propulsive force necessary to lift a rocket against the downward pull of gravity and to accelerate it to a given speed, as specified by the mission. They carry propellants weighing a few tones to several hundred tones. In all the motors used in various launch programme of ISRO, the case material is steel alloy. Solid rocket motors are made with diameter of 10cm to 250cm or more with various port configurations. Essentially a solid propellant rocket motor consists of a rigid case, an internally bonded insulation with liner, igniter, solid propellant and nozzle. The propellant in large motors is adhesively bonded to the liner to provide structural support and to restrict the burning to the core surfaces. Fig.1 shows a typical rocket motor configuration. The motor and the propellant geometry is configured to get a predictable propulsive force. The motor with propellant and interface need to be defect free for ensuring the predictable performance.

Different types of defects like crack, voids, separation between propellant and insulation or inhibition and anomalies in end inhibition may result in a catastrophic failure of the flight.

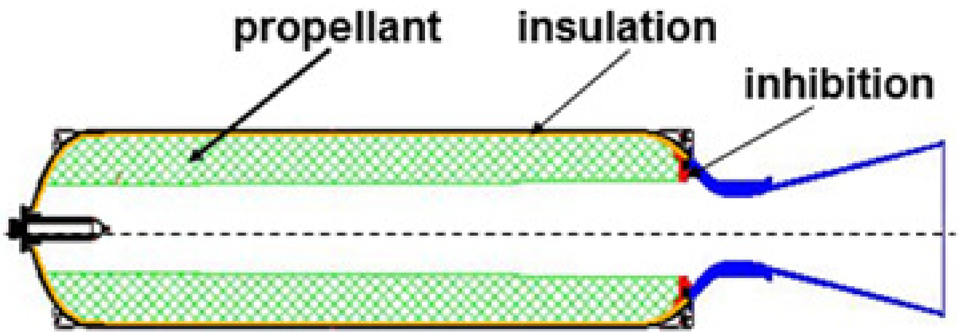

Fig.1 Typical rocket motor configuration

2.0 Radiography of Solid Rocket Motors

Radiography is one of the most versatile quality assurance tool used for the detection and estimation of propellant defects. There are several factors such as radiation energy, source to film distance, size of film grains etc. influencing the quality of radiographs taken. The radiographic inspections of solid rocket motors are complicated compared to welds and castings, due to its large thickness, complex configuration of different materials and also the abundance of low density materials. Large rocket motors above 300 mm diameter are inspected by high energy radiography techniques [1]. Normally two radiography methods are used (1) tangential radiography, to inspect the interfaces between case/insulation/propellant and (2) grain or normal radiography to detect flaws in the propellant grain. Several radiographic exposures are needed in the longitudinal and circumferential directions for inspecting a large rocket motor. The number of exposures is determined based on the crack detection probability criteria and the criticality of defects at various regions [3]. Radiography set up of a large solid motor is shown in fig.2

Fig.2 Radiography setup of a large solid rocket motor

3.0 Defects in solid propellant and analysis

The common defects noticed in solid motors are voids, crack, porosity in loose flap filled resin, separation between propellant/end inhibition/insulation, porosity in inhibition, void in insulation, propellant trimming defects etc.

3.1 Voids

Voids appear as denser spots in the radiograph. From the basic density of the radiographic film if dark spots are seen, it indicates that the effective web of the grain at that radial location corresponding to each dark spot is less than from the normal web. This can be due to presence of a single void or number of voids in a line. With naked eye it will not be possible to assess the intensity of darker spots. Density of the darker spots should be compared with the density of normal region. Film densitometer is used to compare the density of different regions [2]. Basic film density varies based on the type of film, exposure time, developing condition, etc. A typical radiograph of void in a large rocket motor is shown in fig.3.

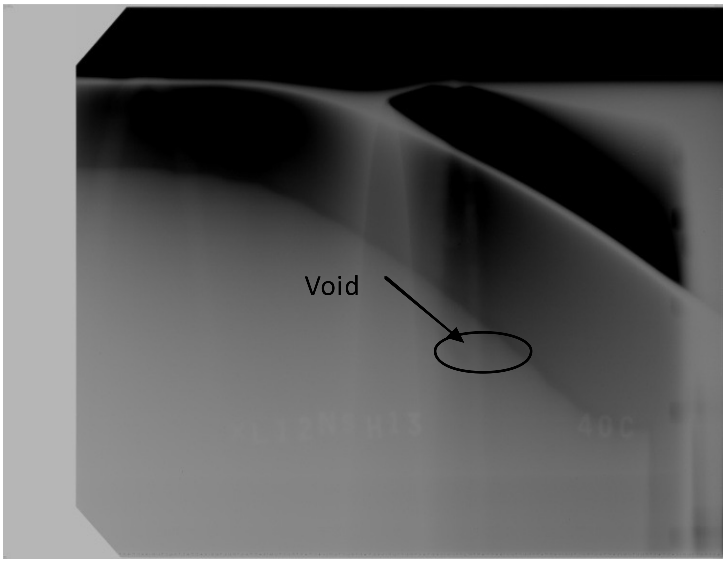

Fig.3 Void in propellant - Initial x-ray image

Normal grain shots reveal the presence of voids if any in the volume covered. For finding the radial location of the voids, triangulation method is followed. In this method additional shots are taken at an angle from below and above the defective region. Then the radial location of the void region can be determined from the three different shots by geometric calculations. Fig 4 describes the details on triangulation shots. Numbers of film markers are kept at 100mm interval and D&U are markers on the motor case corresponding to axial boundary of the defective region as seen in the normal shot. Down shot is centered on D mark and upshot on U mark. From the appearance of defective region in the three shots radial extent at that location can be geometrically estimated.

Another method for finding radial dimension of the void is by taking tangential shots. In this method the void which covered in the grain shot, rotated in small increments and finally positioned as tangent region. By taking the tangential exposure the minimum distance between the void and the insulation and the distribution of the voids were obtained.

With digitization and image processing techniques using a film digitizer, the sharpness and the contrast of the image can be enhanced. Fig 5 shows the propellant void after enhancement.

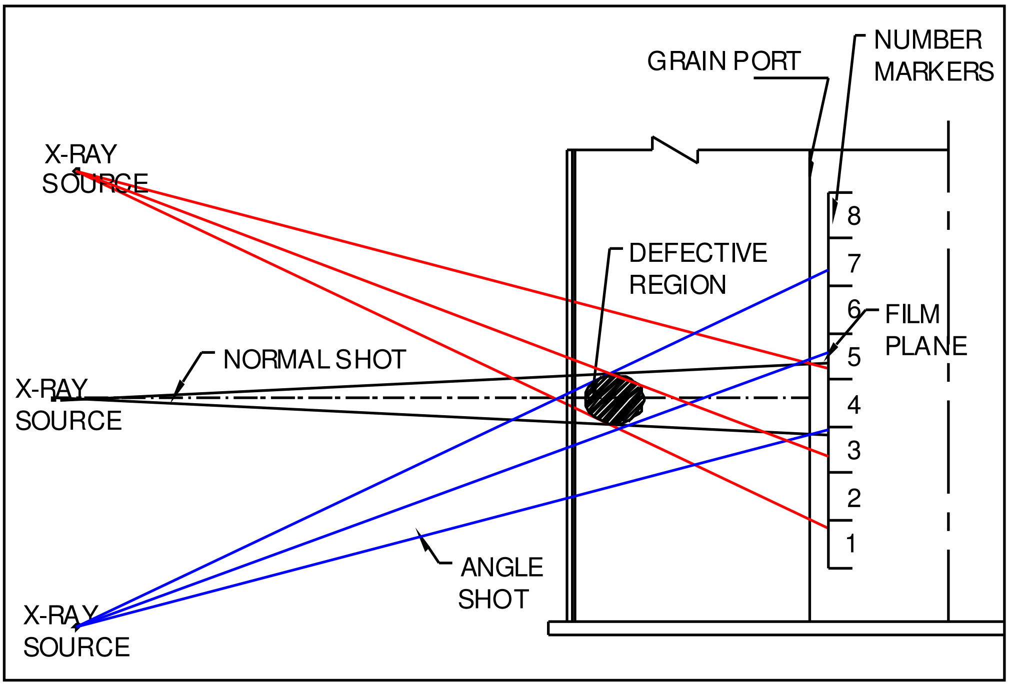

Fig.4 Details of triangulation shots to locate radial extent of void

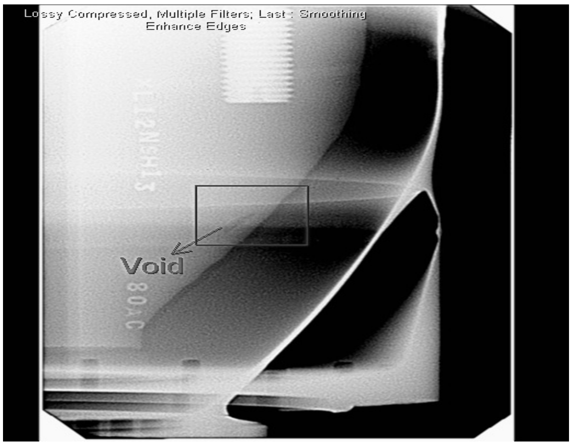

Fig.5 X-ray image after enhancement

3.1.1 Propellant void with tail

In some cases the voids are noticed with tail on the lobe in the axial direction. These defects were observed in free-standing propellant grains processed with pvc-plastisol based composite propellant. Fig.6 shows a propellant void with tail. The reason for the characteristic shape of such defects could be traced to the high temperature physical curing process. Voids in the propellant are released and moved towards the head region while heating. Due to the initiation of curing process the propellant viscosity increased and the voids were entrapped in the propellant with tail. If the tail has a sharp corner, there would be a chance for crack initiation. In such cases, voids having sharp corner or elongated shape in the radial direction shall not be accepted.

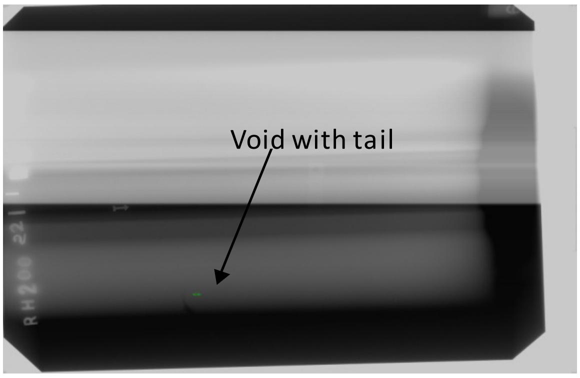

Fig.6 X-ray image of a void with tail

3.1.2 Cluster of voids

Closely spaced voids are normally considered as single void of overall size equal to the linear dimension covering the outer periphery of these voids [4]. 'Cluster of voids' or porosity observed in some of the rocket motors could be correlated to presence of moisture in the propellant slurry or entrapment of air in the insulation free flap. Small single void shall be acceptable irrespective of their location and shape. Cluster of voids can cause early exposure of the insulation and makes the case thermally critical. Structural failure is expected when the voids are very close to each other. Since the size of the voids which are noticed as cluster in nature shows very low density compared to the large single void. Detailed investigation in density variations is essential for the estimation of these defects. Rotate the voids region towards the tangent and took tangential shots in higher density so that RT can ensure the region of cluster of voids whether it is in propellant or inhibition. Fig.7 shows the radiograph of cluster of voids in solid propellant.

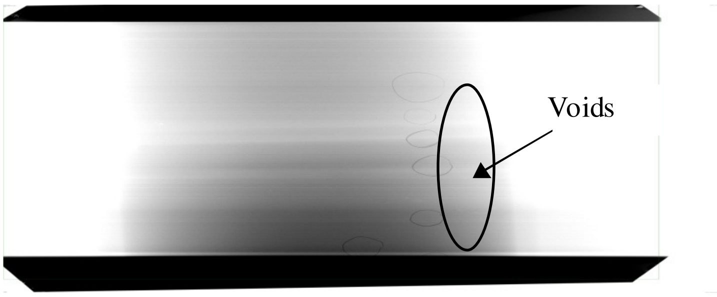

Fig.7 Radiograph of cluster of voids

3.2 Propellant entrapment

Propellant entrapment in the loose flap is another major defect occurred in the rocket motors. Rocket motor cases are insulated with rubber to prevent the transferring of high temperature during burning of solid propellants. Loose flaps are provided in the motor cases to accommodate the shrinkage of propellant during curing. In finishing operation these space are filled with resin. Due to improper filling of loose flap gaps voids may appear between loose flap and fixed insulation. If the voids are noticed at less than 25mm from igniter port opening, that region has to be refilled with resin [4]. A typical radiograph of propellant entrapment in the loose flap region is shown in fig.8

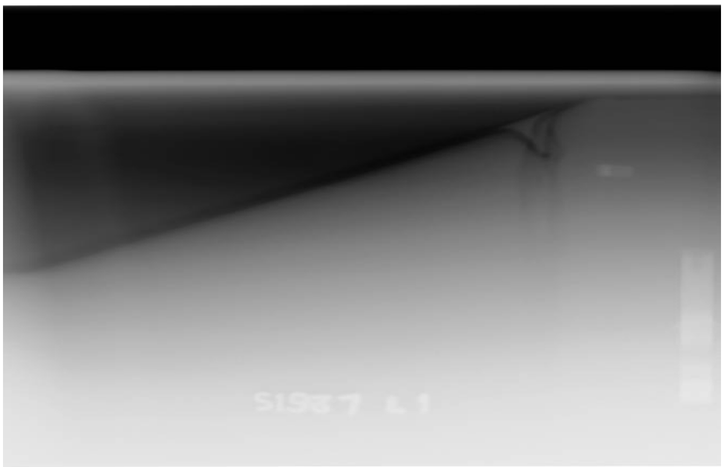

Fig.8 Propellant entrapment in loose flap

3.3 Defects in loose flap filled resin

At the time of casting suitable vents are punched in the loose flap region for the removal of air. In some occasions the propellant traces may be entrapped in the loose flap and detected through radiography. Figure 9 shows a radiograph having few voids in the loose flap filled resin.

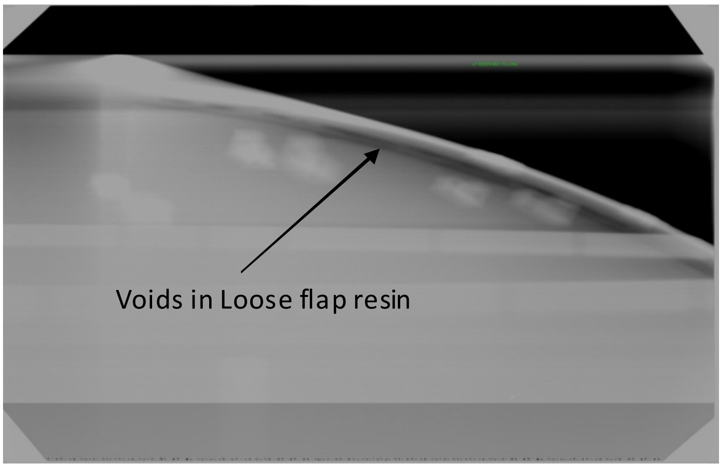

Fig.9 Digitized images of voids in the loose flap filled resin

To detect the entrapment in loose flap tangential shots are taken using the slow speed films. The fine grains of film shows the minute details of the propellant entrapment in detail and the extension of the defects can be plotted by taking required tangent shots of that region. An arrow marker can be placed at the tip of propellant and the circumferential shift of the arrow gives the length of the defect. Tangential shots also gave the information on the depth of propellant traces in the loose flap region.

3.4 Separation between propellant and insulation

Separation between propellant and insulation is not acceptable in any solid rocket motors. The separation between propellant and insulation are considered critical and separation in the dome portion are viewed more serious than that occur in the cylindrical region. The delectability of separation depends upon the number of tangential exposures taken around the motor. Normally, separation is occurred due to the poor storage condition of the motor for a

long period. Normal practice observed during storage is the rotation of the case in a fixed interval. This rotation prevents the sagging of the propellant in one direction and prevents the tendency for separation.

Any separation between the insulation and propellant can be evaluated by using tangential radiography technique. The thickness of material to be penetrated at the insulation casing and propellant insulation interface is calculated in terms of equivalent propellant thickness. This value is used to select the required penetrameters or image quality indicators for tangential radiography.

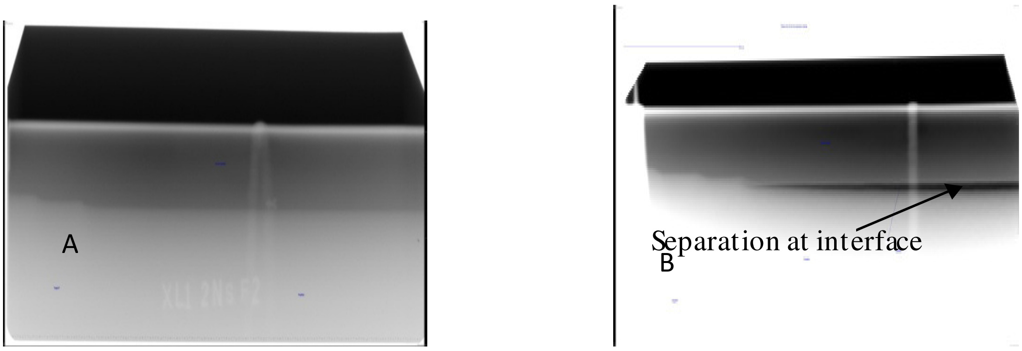

Fig.10 Radiograph of propellant/insulation interface

The X-ray beam is focused at the interface and the film is positioned close to the motor. Fig 10-A shows the radiograph of propellant insulation interface. Due to the poor storage the interface got separated in a motor which is shown in figure 10-B.

3.5 Porosity in inhibition

Both ends of the rocket motor are inhibited by curing of resin. End inhibition prevents the unwanted radial burning of propellant. Porosities are normally noticed in inhibition layers due to the entrapment of gases during the mixing of resin. Porosities on the top surface of end inhibition and between layers are acceptable. Fig.11 shows the radiograph of porosity noticed at the interface of propellant and inhibition. If severe porosity is present at the propellant interface, re-inhibition should be carried out. Film densitometer is used to compare the density of porosity region for the classification purpose.

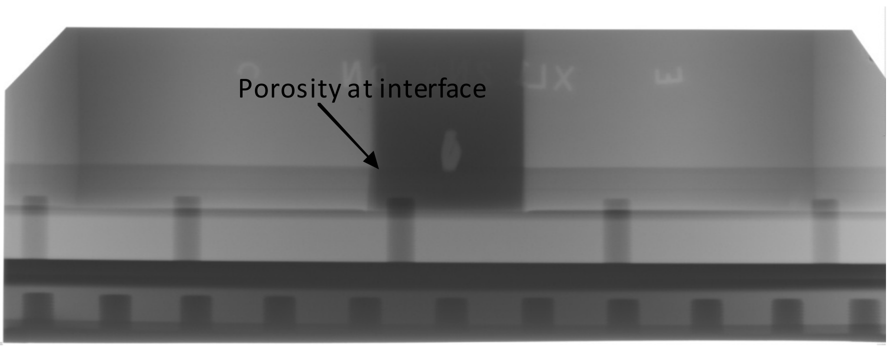

Fig.11 Radiograph of porosity noticed at the interface of propellant/inhibition

4.0 Conclusion

Radiography is the best NDT tool for solid rocket motors. The choice of suitable and accurate radiographic technique and thorough film interpretation is essential for effective defect detection. Various types of defects noticed in the past radiographic inspection has been evaluated. The advancement of digital imaging techniques have shown definite advantages over the conventional radiography techniques in terms of precise detection, location and sizing of defects. Some of the defects such as cracks, voids and porosity in propellant can be eliminated by process control. Some of them occur due to long storage. Propellant cracks shall not be acceptable. Large voids in propellant region shall be accepted by studying the effect of ballistic /structural integrity.

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